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Estimating the age composition of discards in the NAFO 4T American plaice fishery

Estimation de la composition d'âge des rejets dans la pêche de la plie canadienne de l'OPANO 4T

R. Morin

Fisheries and Oceans Canada / Pêches et Océans Canada
Gulf Fisheries Centre / Centre des pêches du Golfe
P.O. Box 5030 / C.P. 5030
Moncton, N.B.
E1C 9B6

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ABSTRACT

Discarding of American plaice by the mobile gear fleet in NAFO Division 4T was widespread until appropriate management measures came into effect in 1994. To assess the status of the resource, it is necessary to develop a commercial catch at age that incorporates both the landed and discarded catches. This study was undertaken to estimate the size and age composition of American plaice discarded by mobile gear from 1976 to 2009. The method used to estimate discards combined length frequencies from landed catches with research survey length frequencies and retention ogives for the dominant mesh size used in the fishery. The approach was modified to take into account the distribution of the fishing fleet and the potential effect of unspecified flounder catches in the 1970s. Annual estimates of discards, as a percentage of the number of plaice caught, averaged 76% from 1976 to 1993 assuming a uniform distribution of catches within 4T, 12% after 1993. The estimated rate of discarding was comparable to at-sea observer estimates for 1976, but less than observed discarding in three of four other comparisons from 1984 and 1990-1992. On the basis of minimum mesh sizes imposed since 1993, discarding should be minimal and may be overestimated in this study. However, estimates for the 1976-1993 period may be less than what occurred in the fishery.

RÉSUMÉ

La remise à l'eau de plies canadiennes par la flotte d'engins de pêche mobiles de la division 4T de l'OPANO était très répandue avant l'entrée en vigueur de mesures de gestion adéquates en 1994. Pour évaluer l'état de la ressource, il est nécessaire de mettre au point un modèle de prises commerciales par âge, qui tient compte à la fois des prises débarquées et des prises remises à l'eau. La présente étude a été entreprise pour estimer la composition selon l'âge et la taille des plies canadiennes remises à l'eau par des engins mobiles entre 1976 et 2009. La méthode utilisée pour estimer les remises à l'eau associait les fréquences de longueur des prises débarquées aux fréquences de longueur des relevés de recherche ainsi que des courbes de rétention correspondant au maillage dominant utilisé dans le cadre de cette pêche. La méthode a été modifiée pour tenir compte de la distribution de la flotte de pêche et des effets possibles des prises de plies non précisées dans les années 1970. Les estimations annuelles des remises à l'eau, en tant que pourcentage du nombre de plies canadiennes prises, étaient en moyenne de 76 % de 1976 à 1993, si on suppose que la distribution des prises était uniforme dans la division 4T, et de 12 % après 1993. Le taux estimé de remise à l'eau était comparable aux estimations réalisées par des observateurs en mer en 1976, mais inférieur aux remises à l'eau observées dans trois des quatre autres comparaisons pour 1984 et 1990-1992. En se fondant sur les maillages minimaux imposés depuis 1993, la remise à l'eau devrait être minime et pourrait être surestimée par la présente étude. Ainsi, les estimations pour la période de 1976 à 1993 pourraient être inférieures à la réalité de la pêche.

INTRODUCTION

The number of fish caught and landed in a commercial fishery, in addition to their size and age composition, form the basis of analyses required to manage fisheries. When fish caught are discarded at sea, usually because they are smaller than the marketable size, landed catches no longer reflect total removals and uncertainty results for the management of the resource.

American plaice in NAFO Division 4T (Fig. 1) could be regarded as an example of how discarding can impact what we know of a fishery, from landings to the scientific advice required to manage the fishery. The at-sea discarding of plaice in the 4T trawl fishery first drew attention in the late 1950s, but despite increases in mesh size, there was little improvement in the level of discarding by the 1970s and 1980s. An annual quota of 10,000 tonnes was imposed in 1977 on 4T plaice and remained at that level until 1992, even as stock biomass declined in the 1980s. Stock assessments during that period noted that any reduction to the quota would only incite more discarding in the fishery (Tallman and Forest-Gallant 1990). Uncertainty in the catch-at-age due to discarding made it impossible to successfully model population trends by conventional methods, such as sequential population analysis (Morin et al. 2001), further affecting the advice required for management of the resource.

In 1993, the 4T Atlantic cod fishery was closed to commercial fishing and a new era of fisheries regulations came into effect. Several management measures were applied to the 4T plaice fishery after 1993: reduced quota, mandatory landing of all fish caught, increased mesh size, minimum fish size regulations, increased observer coverage, dockside monitoring and by-catch limits on cod and other groundfish. These measures are reviewed in the following section.

In the late 1980s, technical reviews of the 4T plaice stock assessment recommended an approach to estimate the size and age composition of discards in the absence of extensive and annual observations of discarding at sea. Tallman (1991) presented a method that estimated discards by combining the observed size composition of commercial landed plaice with the research surveys of plaice that had been "fished" by retention ogives for mesh sizes used in the commercial fishery. This report updates estimates of discarding using the method presented by Tallman (1991) and presents a revised catch-at-age for the commercial fishery since 1976.

NAFO 4T AMERICAN PLAICE FISHERY

Otter trawling was introduced to groundfish fisheries in the southern Gulf of St. Lawrence in 1947 (Jean 1963). The growth of trawling, followed by the introduction of Danish seining in 1958 (Powles 1969), resulted in rapidly increasing catches of American plaice. By 1965, plaice landings in 4T, not including discards, were over 10,000 tonnes (Morin et al. 2008), with trawls and seines accounting for over 90% of landed catches since then.

Table 2 shows the reported landings by the main gear types since 1976, the year that the DFO began systematic sampling of the size and age composition of landed catches of 4T plaice. Until the early 1980s, some landings in 4T were specified as "unidentified flounder". Powles (1969) estimated plaice landings, taking into account the expected species composition based on survey data. He reported that survey catches in the northern Magdalen Shallows were composed of 90% plaice and about 80% plaice in the southern half. The International Commission on North Atlantic Fisheries (the precursor of NAFO) revised landing statistics for 1963-1972 to account for unspecified flounder (ICNAF 1974), without specifying how the corrections were made. For this report, plaice landings were augmented by 90% of unspecified flounder landings, as an upper limit to plaice landings. In this report, the catch-at-age is

estimated with and without unspecified flounders for 1976 to 1983, along with associated discards by mobile gear.

The first quota regulation for 4T plaice was imposed in 1977 at 10,000 tonnes. Until 1977, there were few measures taken to regulate the fishery. Beginning in 1947, trawlers adopted a 75-mm (3-inch) codend mesh size, but by 1959 most had adopted 114 mm (Powles 1969). There is some uncertainty as to what mesh sizes were used in plaice fisheries during the 1970s and 1980s. Clay et al. (1984) reported that up to 1976, the minimum codend mesh size was between 105 and 114 mm, depending upon the type of twine. In 1977, the minimum mesh size became 120 mm for most materials, and in 1981, it became 130 mm. Chouinard and Metusals (1985) reported the same mesh sizes in use and Tallman (1991) assumed these mesh sizes for his estimates of plaice discarding. However, Halliday et al. (1989) considered that, between 1976 and 1979, seiners should have used a minimum codend mesh size of 110 mm and trawlers should have used a minimum of 130 mm.

As previously stated, the closure of the 4T cod fishery in 1993 provoked a number of management measures affecting the plaice fishery. The plaice quota dropped to 5,000 tonnes, partly due to concern that vessels previously targeting cod would redirect their effort to other groundfish stocks. By 1993, and in ensuing years, other measures were introduced that either directly prevented discarded, or indirectly, though increased surveillance, made it more difficult to discard fish at sea.

- Mandatory landing of all fish caught (i.e. discarding became a violation).
- Mesh size increases.
- Minimum fish size regulations resulting in area closures when the number of fish caught below the minimum size was more than 15% of the catch.
- Observer coverage on 25% of trips in the directed plaice fishery.
- Dockside monitoring of all catches with mandatory notification on leaving and returning to port.
- By-catch limits on cod and other species in the plaice-directed fishery.

Data on mesh sizes in the 4T fishery since 1987, based on available electronic files of the southern Gulf observer program, reflect how the fishing industry implemented the regulatory changes that occurred during the 1990s (Fig. 2). Vessels directing for plaice in 4T from 1987 to 1992 predominantly used 130-mm diamond mesh. The same analysis (not shown) for 4T cod-directed fishing also indicated that 130-mm diamond mesh was the dominant mesh size from 1987 to 1992. In 1993, 130-mm square mesh was proposed for cod-directed fishing. The observer data indicate that the industry complied by shifting to 130 mm square mesh, with some vessels adopting larger mesh sizes. In 1994, 145-mm square mesh was recommended, but many vessels continued to adopt larger meshes. By 1995, 152-mm mesh (6 inches) was required and, in 1996 until present, 155-mm square mesh has been the minimum requirement for plaice-directed fishing in 4T. Throughout the 1990s, the fishing industry responded to changing mesh size regulations, either accepting that minimum or adopting larger mesh sizes (Fig. 2).

DATA SOURCES

OBSERVER DATA

Before 1994, when it became mandatory to land all plaice caught at sea, discarding was periodically assessed by deploying observers on fishing vessels. The Gulf Region Observer Program was introduced in 1981 to observe the domestic and French fleets in NAFO divisions 4RST and 3Pn, providing data and information required for stock assessment and management, but also monitoring the compliance of fleets with current regulations (Kulka and Waldron 1983). Observer data also contribute to the biological assessment of 4T plaice by augmenting the sampling that is made in landing ports (Morin et al. 2008).

Although biologists drew attention to discarding in the 4Tplaice fishery in the 1960s, it appears that observers were not thereafter deployed in any consistent manner. Table 1 summarizes the published estimates of the weight and the number of discarded plaice as a percentage of the total catch. All of these estimates were based on at-sea observed catches, sometimes combined with port sampling of either the same vessels or catches from vessels in the same fishing area. With the exception of the studies in 1976 and 1984 (Halliday et al. 1989, Chouinard and Metusals 1985, respectively), most of the estimates were made with relatively few fishing trips in restricted areas of the southern Gulf fishery.

Observer data in electronic files for the southern Gulf are currently available yearly since 1990. The data from 1984 used by Chouinard and Metusals (1985) were transcribed to electronic files for this study. Of the 10 trips that were reported from their study, our data files record nine; however, our estimates of discarding are similar to those in Chouinard and Metusals (1985). Discarding estimates were also compared with the results of at-sea observers in 1984 and 1990-1992. In the latter three years, observers recorded discarding by vessels directing for American plaice in 4T on six vessel trips in 1990, 13 trips in 1991 and 9 trips in 1992.

PORT SAMPLING

Since 1976, commercial catches of plaice in 4T have been sampled at landing ports throughout the active months of fishing (Morin et al. 2008). The sample requirements consist of sexed length frequencies, with otoliths removed for age determination at a sampling rate of one per sex, per cm length. In all cases, the location of the capture and the weight of the catch are recorded and corrections are applied when the catch was graded by size or category. Length-weight relationships established from annual research surveys are used to convert numbers-at-length of male and female plaice to estimates of the sample weight.

Separate age-length keys are determined for seines, trawls and fixed gears (mainly longlines and gillnets). Keys are further separated into two seasons, up to and after July 31, to account for growth changes. A description of the sampling up to 2007 may be found in Morin et al. (2008).

RESEARCH SURVEYS

Groundfish stocks in 4T have been surveyed by experimental trawling every September since 1971 using a stratified random design (Hurlbut and Clay 1990). The survey area was initially divided into 24 strata, mainly on the basis of depth and fish distribution. In 1984, three inshore strata were added to the survey (Fig. 3), but these are at the margin of plaice habitat and are not used for analyses of plaice abundance and size distribution.

The survey provides a continuous time series of abundance and size and age composition of 4T plaice. Any changes to the trawl or the survey vessel have been accompanied by comparative fishing experiments wherein the old and the new gear or vessel were fished in parallel (Benoît 2006). An exception to this is the survey of 2003, when mechanical failure of the survey vessel resulted in a non-calibrated vessel being used. Time limitations also caused two strata to be missed and another two to be sampled with only one trawl set. As a result, the 2003 research survey has been dropped from the time series for all groundfish stocks.

Most sampling procedures in this survey have remained constant since 1971 (Hurlbut and Clay 1990). The length frequencies of plaice have been sex-based, with the exception of three years (1984-1986) when sexes were combined. Sampling for biological information, such as age and maturity, is conducted at a rate of one sample per sex, per cm length.

ANALYSES

Tallman (1991) presented a general approach to estimating the number of discarded fish at age in the 4T plaice fishery. This approach can be summarized in four steps:

1. Obtain the research survey population-at-length for 4T plaice in a given year and the landed catch-at-length for mobile gears (trawls and seines) in the same year, based on port sampling and observer data.
2. Obtain published retention ogives for the required (or dominant) mesh size for each year of the fishery. These ogives estimate the proportion of plaice of any given length that is retained by that mesh size. Multiply the survey population-at-length by the appropriate retention ogive. This effectively "fishes" the survey population to generate a theoretical length frequency distribution of plaice (TLFD) for the fishery in a given year.
3. Scale the TLFD to the landed catch-at-length across lengths that are not discarded by the fishery. The difference between the scaled TLFD and the landed catch-at-length is the length distribution of discarded plaice in that year's fishery.
4. Convert the discarded length frequency to male and female length frequencies based on the research survey sex ratios at each length. Apply the annual research survey age-length key for each sex to estimate the age composition of discards.

At step 1, the research survey is assumed to provide an unbiased representation of the size and age structure of the 4T plaice population. Clay (1979), cited by Tallman (1991), estimated that the 6-mm codend mesh that was used in the survey trawl from 1971 to 1985 (increased to 19 mm in 1986) would retain 50% of plaice of 7 cm in length. In fact, the modal size of plaice has averaged 24.5 cm from 1971 to 2007 (range 18-28 cm), suggesting that plaice may not become fully recruited to the survey trawl gear, possibly by about 25 cm. Any under-representation of plaice in the survey at sizes of 22 to 25 cm would potentially under-estimate discarding, particularly at mesh sizes of 110 and 120 mm. At those sizes, a 110-mm mesh retains between 9% of plaice of 22 cm and 43% of plaice at 25 cm; at 120 mm, plaice are retained at 3 and 17% for corresponding sizes.

Retention ogives for 110 and 120-mm meshes were taken from Clay et al. (1984). The selectivity of four meshes for American plaice was studied for Scottish seiners in the southern Gulf in 1993 (Tait 1993). That study was the origin of retention ogives for 130-mm square and diamond meshes and the study of Walsh et al. (1992) for 155-mm square mesh. Codend mesh sizes were assumed to be 110 mm in 1976, then 120 mm from 1977 to 1980 and 130 mm diamond from 1981 to 1992, as described by Clay et al. (1984), Chouinard and Metusals (1985) and used by Tallman (1991). However, discarding was also estimated using the gear-specific

codend meshes suggested by Halliday et al. (1989) from 1976 to 1979: 110 mm for seines and 130 mm for trawls. The dominant mesh size for the 1993 directed plaice fishery was 130-mm diamond (Figure 2), as required in the management plan for that year. I assumed a codend mesh size of 155-mm square since 1994.

For each mesh size, the proportion of plaice retained at each length, *r(l)*, was modelled with a logit function:

$$r(l) = \frac{\exp(k(l - l_{0.5})/s_r)}{1 + \exp(k(l - l_{0.5})/s_r)}$$

where k is the constant 2*ln(3) = 2.197, $l_{0.5}$ is the length at which 50% of plaice are retained, $s_r = l_{0.75} - l_{0.25}$ (the difference between the length at which 75% and 25% of plaice are retained). The theoretical length frequency distribution of the fishery (TLFD) in a given year was obtained by multiplying the research survey population-at-length by *r(l)* for the appropriate dominant codend mesh size for the fishery in the same year.

The third step in the analysis involved rescaling the TLFD to be equivalent to the observed landed catch-at-age for the fishery in the same year. Tallman (1991) proposed to do this by multiplying the TLFD by the ratio of the sum of theoretical and observed catches across a range of non-discarded lengths. He proposed a lower limit of 40 cm for non-discarded plaice and an upper limit of 60 cm, beyond which sampling may be sporadic. Powles (1960), Chouinard and Metusals (1985), and Halliday et al. (1989) all reported that plaice were discarded mainly up to 35 cm in length. However, some authors (Cliche and Côté 1984 and Chouinard and Metusals 1985) also observed significant levels of discarding at lengths between 35 and 40 cm. The same range of sizes as Tallman (40-60 cm) on which to adjust the TLFD was chosen for the period up to 1993. Adjusting the TLFD on plaice lengths between 35 and 60 cm effectively reduced the overall level of discarding estimated, usually by within 5%.

Fishery regulations were imposed in 1994 that set limits on the number of plaice of 30 cm and less that are caught in the 4T fishery. With dockside monitors verifying the size distribution of each catch, it seemed reasonable to assume that any discarding after 1993 would have occurred at no more than 30 cm in length. However, the size range of non-discarded plaice was restricted to 32 to 60 cm for the period 1994-2009. Moving the lower limit for adjusting the TLFD from 30 to 32 cm also tended to increase the estimates of discarding by less than 3%.

In addition to scaling the TLFD to the landed catch-at-length, an alternative approach of regressing the landed catch-at-length against the theoretical number of non-discarded fish was used. The slope of this relationship, with no intercept, provided similar estimates to the catch ratio method proposed by Tallman (1991). The slope of the regression of catches indicated how well the two length distributions (theoretical and observed catch-at-length) correspond over non-discarded lengths. The regression method also made it possible to test the assumption that the theoretical catch is related to the observed catch as a linear function, independent of fish length (an assumption that would be implicit in using the ratio of the two variables to scale the TLFD). By resampling with replacement the regression of the observed catch-at-length on the TLFD, confidence limits were determined for the estimates of discarded plaice.

The length composition of discarded plaice was estimated by subtracting the observed landed catch-at-length from the scaled TLFD. Negative values were set to zero and an upper size limit for discarded plaice was set at 40 cm, beyond which any (always small numbers) of discarded plaice were also set to zero.

Up to this point, discarding was estimated on the total catch of plaice, sexes combined. The sex composition of discarded plaice was then estimated by the ratio of female: male at each cm in the research survey data. The sex ratios in the 1984 to 1986 surveys, when plaice length frequencies were not sexed, were estimated by a local regression model (loess) with year and length factors. The model was based on the proportion of females observed five years before and five years after the 1984-1986 period. Predicted values of the female proportion were generated over the three years (1984-1986) and lengths of 10 to 68 cm.

The age composition of discarded plaice was determined by applying the annual age-length keys for male and female plaice obtained from the research surveys to the length composition of discards.

SPATIAL EFFECTS

Tallman (1991) noted that the fleet exploiting American plaice does not fish throughout 4T with uniform intensity. The TLFD estimated in the manner described above assumes, on the contrary, that the fishery is conducted uniformly throughout 4T or that there are minor local differences in the size composition of plaice. He proposed a modification that takes into account the spatial distribution of fishing by NAFO unit area (Figure 1).

The method involves, first, taking the research survey population-at-length in each stratum and converting this to the population-at-length in each unit area. Knowing the coordinates of the boundaries of each stratum *i* and each unit area *j*, it is possible to calculate the proportion of the area of a stratum that contains any given unit area, P_{ij}. The population at each length in unit area *j* that is within stratum *i* is obtained by multiplying P_{ij} by the research survey population (N_i) in stratum *i*. The total population in unit area *j* (N_j) can then be obtained by summing across all strata.

$$N_j = \sum_i (N_i \cdot P_{ij})$$

The theoretical length frequency distribution, corrected for fishing activity, is then calculated by weighting N_j by the landings that occurred in unit area *j*:

$$\sum_j (N_j \cdot Q_j)$$

where Q_j is the proportion of annual landings occurring in unit area *j*.

The decision of whether or not to correct the TLFD for fishing activity depends on a number of factors. The research survey is conducted every September when plaice are dispersed throughout the southern Gulf, before they move into channel waters to overwinter. If 4T plaice were segregated geographically by size, age or sex during the survey, the distribution of the fishery would be expected to influence estimates of discarding by the method proposed in this study. This would be a reason for applying a spatial correction to the TLFD. However, if the 4T fishery was conducted at times of the year when plaice are not dispersed (e.g. in early spring during movement into the Gulf and spawning, or in late fall when plaice move offshore), the size composition of plaice in the research survey would be unrelated to the population exploited by the fishery during these periods. The proposed spatial correction to the TLFD would not be able to resolve this effect. The approach adopted for this study was to estimate discards by comparing the results with and without correcting the TLFD by the spatial effect of fishing activity.

RESULTS

Unidentified flounder catches in 4T that could be assigned to American plaice contributed up to 12% of the recorded landed catch between 1976 and 1983 (Table 2). In that period, gillnets or unspecified gear contributed most of the unidentified flounder that were considered to be plaice. For mobile gear, from which discarding was estimated, unidentified flounder increased the reported plaice landings by, at most, 3%. The commercial catch-at-age (Table 3) was also revised for the 1976-1983 period to include plaice reported as unspecified flounder (Table 4). The increase in the numbers of landed plaice reflect the change in the weight of the landed catches, ranging from 4 to 13%, with the exception of 1981 when unspecified flounder catches would have increased the reported landings by only 1%.

Across lengths of plaice that were assumed not to be discarded (40-60 cm before 1994; 32-60 cm, 1994 on), the regressions of the observed length frequency on the theoretical catch-at-length were highly significant, with coefficients of determination (R^2) exceeding 0.85 in most years (Table 5). The exception was the 2008 fishery, for which there was no significant relationship between the estimated and observed abundance at lengths assumed not to be discarded. Despite the high level of R^2 in Table 5, a closer examination of the relationship between the theoretical and observed catches at each length revealed that after 1993, the relationship was distinctly curved (Figure 4). Since Figure 4 pairs commercial and theoretical catches at each fish length, with highest catches at the smallest lengths, a linear regression on data after 1993 will tend to estimate a higher commercial catch than observed at small sizes. The estimation of discarding used an adjustment of the TLFD based on a linear relationship between theoretical and observed catches at 32-60 cm after 1993. However, the lack of a linear relation across all non-discarded lengths will result in some degree of overestimation of discarding of small fish.

Discarding estimated using the model that takes into account the distribution of the plaice fishery by unit area (the area effect) varied more widely from year to year than the model without the area effect (Table 5). From 1976 to 1993, discarding averaged 58% annually with the area effect model, with a coefficient of variation (CV) of 26%. Without the area correction, discarding averaged 76% annually over the same period, with a CV of 12%. From 1994 to 2009, the two models produced very similar estimates of discarding, averaging 12% and with CV's of 52 to 53%. The estimates of discarding by the area-effect model produced anomalous results for 1984 and 1986 (discarding <30% by number, Table 5). This result for 1984 is well below the estimate obtained by observed catches in 4Tklng in the same year (61%, Table 1).

Much of the discrepancy between the two modeling approaches can be accounted for by uncertainties in the landings by NAFO unit area until the 1990s. Logbooks only became a condition for licensed fishing of groundfish in the southern Gulf in 1991. Between 1976 and 1990, there were 11 years when over 20% of annual plaice landings were made without a record of the unit area in which the catch was made (labelled "unknown" in Figure 5). In the early 1990s, the plaice fishery became increasingly concentrated in the eastern half of 4T, unit areas 4Tfg, as opposed to areas 4Tklmn in the western part of 4T (Figure 5). However, given the high proportion of landings before 1991 that could not be attributed to any unit area, it is unreasonable to apply the area correction to discard estimates. From 1991 onwards, the two methods of estimating discarding produced similar results, differing by less than 2% in most years (Table 5, Figure 6). Up to 1990, discarding estimates based on the correction due to fishing area led to variable and, at times, unreliable estimates of discarding. I proceeded with estimates of discarding with a model that does not adjust the estimated population numbers-at-length by the catch levels in unit areas up to 1990 and a model that makes this adjustment from 1991 onwards.

Discarding estimates were also made using the mesh sizes that Halliday et al. (1989) considered to be possibly in use from 1976 to 1979. Table 6 shows the estimates of discarding, assuming that 110-mm codends were used by seines and 130 mm used by trawls during those years. The model used for these estimates assumed no area effect, therefore similar to the last column in Table 5. Discarding rates dropped using this choice of mesh sizes and were considerably less than the discarding rate reported by observers to be 74% Halliday et al. (1989). A similar estimate of discarding was obtained for seines in 1976 (68.5% vs 66% by Halliday et al. 1989), but less than observed discarding by trawlers (48.5% vs 76% by Halliday et al. 1989). I concluded that the 130-mm codend mesh size suggested by Halliday et al. for trawlers was inconsistent with the mesh size reported by other authors to be 110 mm and led to an underestimation of discarding.

Figure 7 shows the adjusted theoretical length frequency distribution for 1976. The area between the two curves, from 10 to 40 cm represents the estimated discards. Halliday et al. (1989) reported that discarding occurred mainly between 20 and 35 cm, with a mode at 28 cm. Similar results are shown for the estimated length composition of discards in 1976, which also obtained a mode at 28 cm (Figure 7). Similar length frequencies, observed and estimated, with the length composition of estimated discards are also shown in Figure 7 for analyses of 1999 and 2006 data. These two years were displayed because they are typical of the pattern observed in estimates made for years since 1993. In this period, the descending portion of the estimated length frequencies is not as well fitted to the observed catch-at-length in the mobile gear fisheries. Given the large mesh sizes that has been used in the fisheries after 1993 (145 and 155-mm meshes), the size range of discards has declined, along with the capture of plaice less than 25 cm.

Comparisons were made of estimated discarding with observations made at sea in the same year. The 1984 data analyzed by Chouinard and Metuzals (1985) indicated a higher rate of discarding in the smaller size range of plaice than estimated in this study, particularly below 30 cm (Figure 8A). Chouinard and Metuzals (1985) reported 61% discarding by number; the estimate provided here is 42.6%. Results were similar in comparisons with observer data from 1990 and1992, with a tendency to both underestimate below 30 cm and overestimate above 35 cm (Figure 8). The comparison for 1991 was unusual both for the observed discarding (low level of discarding observed at <30 cm) and for the estimated discards which overestimated both small and large plaice (Figure 8C, 1991).

The discarded catch-at-age, combining male and female plaice, is presented in Table 7. The discarded catch-at-age dropped sharply in 1994 with the regulatory increase in codend mesh size and declines in landed catches that began in 1993. The modal age of discarding ranged between 6 and 10 years of age, but most frequently 7 or 8 years-of-age from 1976-1993 and 8 or 9 years-of-age from 1994-2009. Estimates of the discarded catch-at-age were also made for trawl and seine catches that would have been identified as unspecified flounder from 1976 to 1983 (lower section of Table 8). Although the landed catch-at-age increased considerably for some years during this period (upper section of Table 8), most of the unspecified flounder were associated with fixed gear. Discards associated with unspecified flounder increased the previously reported landings of plaice by less than 3%.

Table 9 presents the geometric means of discarded plaice at age resulting from 5,000 bootstrap iterations of the linear regressions used to adjust the TLFD to the observed catch-at-length. Over most ages and years, the bootstrap estimates of mean discarding closely followed the initial estimates presented in Table 7. However, Table 10 shows the increase in uncertainty associated with estimates of discarding after 1993, with CV's by more than tenfold (shown graphically for age-10 plaice in Figure 9).

DISCUSSION

In retrospect, it appears that more could have been done to quantify discarding with at-sea observers, particularly when it was known to occur at such a high frequency and level. The early studies of plaice discarding served to identify a serious problem in the mobile gear fisheries; however, they failed to provide a comprehensive estimate of discarding at the level of the 4T fishery. Even the most extensive study documented by Halliday et al. (1989) was based on 47 vessel trips, a fairly modest deployment compared to recent observer programs that assign observers to 25% of vessel trips. In contrast, data on the 1991 and 1992 fisheries (just before discarding regulations came into effect) indicate that over 600 trips were made each year by boats directing for plaice in 4T with mobile gear.

The current observer program in NAFO 4T is not without problems, however. Benoît and Allard (2009) demonstrated that observers are not deployed randomly across all active vessels and that the catch composition of vessels changed in the presence of an observer, suggesting that normal fishing practices are not represented by observed vessels. It is not possible to assert whether the same problems applied to the 4T plaice fishery before 1994. Prior to that year, discarding was permitted and vessels were only required to adopt the minimum mesh size in effect. However, it cannot be assumed that fish harvesters were indifferent to the level of discarding recorded by observers and it may be possible that there was some tendency to minimize discarding in the presence of an observer.

The method applied in this study, based on Tallman (1991) estimates discarding independently of observers. Tallman's method, similar to those of Mayo et al. (1981) and Casey (1996), assumes that a relationship exists between the survey-based length composition of a fish population, adjusted for the mesh size of commercial gear, and the discarding of a commercial fleet exploiting the same population. I have shown that over 24 years in the 4T plaice fishery, with few exceptions, a significant relationship may be found for non-discarded lengths. However, this relationship was questionable for the period since 1994 and it may have resulted in an overestimation of recent discarding of plaice.

Although not the basis for these estimates, empirical observations at sea are required to validate the method. In the period when discarding was widespread, observer deployment was minimal; since 1994, any vessel inclined to discard plaice in 4T would not do so in the presence of an observer without risking a violation. The estimate of discarding in 1976 compare favourably (although only qualitatively) with the results of Halliday et al (1989). Compared to observer studies in the 1980s and early 1990s, my results tended to underestimate discarding at less than 30 cm and possibly overestimate at larger size of 35-40 cm.

One of the limitations of the method used in this study is that it estimates discarding solely on the basis of the expected catch due to the mesh size in use at the time of the fishery. The method also relies on the population size structure that is provided by the research surveys which, in turn, may not be fully selective for plaice at small sizes. Partly for these reasons, the results presented here, particularly for smaller plaice (<30 cm) should be regarded as minimum estimates. Mesh size is obviously critical to the size composition of plaice catches; however, it can only account for a portion of discarding. Discarding was also a human activity, practiced with methods and motivated for reasons that may never be fully known.

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Table 1. Summary of observed rates of discarding in the NAFO 4T American plaice fishery by gear, indicating the number of observed vessel trips, based on published field studies. Unit area designations relate to areas shown in Figure 1 (n.s. = not specified; S&T = seines and trawls).

Year	Unit area	Trips	Gear	% discarded by Weight	% discarded by Number	Reference [1]
1957	n.s.	n.s.	trawl		70	*a*
1958	n.s.	n.s.	trawl	34	74	*a, b*
1959	n.s.	n.s.	trawl	64	81	*a, b*
	G	n.s.	trawl	36	70	*c*
	G	n.s.	seine	15	43	*c*
1960	n.s.	3	trawl	34		*b*
1961	n.s.	2	trawl	51		*b*
	N	n.s.	trawl	57	85	*c*
	M	n.s.	trawl	31	54	*c*
	M	n.s.	seine	21	49	*c*
1972	KLN	1	trawl	26	40	*d*
1976	KLMNFG	47	S&T	49	74	*d*
1979	KLN	6	S&T	32	52	*d*
1980	N	6	trawl	25	51	*e*
1981	N	6	trawl	40	68	*e*
1984	KLNG	10	S&T	40	61	*f*

[1] *a:* (Powles 1960); *b:* (Jean 1963); *c:* (Powles 1969); *d:* (Halliday et al. 1989); *e:* (Cliche and Côté 1984); *f:* (Chouinard and Metusals 1985).

Table 2. Landings of NAFO 4T American plaice (tonnes), in addition to 90% of unidentified flounder landings, assumed to be American plaice. Landings are grouped by gear classes: S&T represents seines and trawls; FIX represents fixed gears (gillnets and longlines); OTHER represents other types of minor gears, such as handlines and trap nets.

	Reported plaice landings				90% unidentified flatfish				Landed
Year	S & T	FIX	OTHER	Total	S & T	Fixed	Other	Total	Total
1976	10398	227	568	11193	275	311	14	601	11794
1977	8684	258	288	9230	116	912	19	1047	10277
1978	8093	421	517	9031	85	541	62	688	9719
1979	8178	730	1088	9996	119	621	17	757	10753
1980	7352	779	161	8292	129	0	554	683	8975
1981	6193	1182	459	7834	106	0	0	106	7940
1982	5583	899	60	6542	65	1	244	310	6852
1983	5497	570	27	6094	1	0	712	713	6807
1984	7120	2291	188	9599	26	15	0	41	9640
1985	7969	1401	120	9490	0	3	0	3	9493
1986	6361	975	72	7408	0	0	0	0	7408
1987	6489	1495	80	8064	0	0	0	0	8064
1988	5399	1441	149	6989	0	0	0	0	6989
1989	4600	713	404	5717	29	0	4	32	5749
1990	4154	714	39	4907	11	23	0	33	4940
1991	4551	627	44	5222	12	22	0	33	5255
1992	4566	607	25	5198	15	67	0	82	5280
1993	1217	620	16	1853	22	3	0	24	1877
1994	2129	256	35	2420	0	0	0	0	2420
1995	2223	138	33	2394	5	0	0	5	2399
1996	1352	43	11	1406	0	0	0	0	1406
1997	1666	51	1	1718	0	0	0	0	1718
1998	1112	55	0	1168	26	1	0	27	1195
1999	1428	111	1	1540	0	0	0	0	1541
2000	1366	51	0	1417	3	0	0	2	1419
2001	1155	35	0	1190	0	0	0	0	1190
2002	653	25	0	678	0	0	0	0	678
2003	367	23	0	390	0	0	0	0	390
2004	361	39	0	400	1	0	0	0	400
2005	290	49	0	339	1	0	0	0	339
2006	427	36	11	474	0	0	0	0	474
2007	313	20	39	372	0	0	3	3	375
2008	109	40	23	172	0	0	0	0	172
2009	80	31	15	126	0	0	0	0	126

Table 3 Catch-at-age (thousands of fish) for NAFO 4T American plaice based on sampled commercial catches and reported landings.

Age	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29
4	0	3	15	3	0	64	0	15	40	17	0	1	20	5	72	6	16
5	32	94	385	0	0	68	0	184	224	115	25	52	170	115	105	101	275
6	467	571	1052	419	34	104	29	270	413	85	413	110	355	480	313	274	850
7	1346	2068	2375	1244	364	198	39	376	834	534	681	596	394	1126	711	640	1399
8	2287	2279	4496	4245	1035	862	353	432	917	729	1534	1022	681	1290	1616	759	1794
9	2013	2142	2664	5413	2967	1084	926	445	1061	870	1232	800	1016	1738	1112	1568	1408
10	2374	1717	2702	3751	2290	1308	1512	1056	2010	1306	1421	1356	745	1286	1144	1067	1976
11	2014	1372	2435	2325	2132	1468	1352	818	2116	1844	1563	1186	849	938	847	1023	1191
12	2894	1873	1389	1561	2364	1198	1410	1352	1646	2456	1579	1496	1052	709	621	861	841
13	1523	692	1323	1083	1800	929	1053	1448	983	1702	1626	1516	981	604	609	612	380
14	700	652	863	1141	1317	760	810	792	1164	1410	1044	1540	840	516	409	428	387
15	475	214	533	354	778	1195	415	582	857	962	767	852	661	400	377	292	274
16	534	285	233	244	450	533	403	601	388	734	568	541	649	383	276	303	241
17	284	177	137	154	207	693	292	529	402	513	325	468	392	282	199	325	112
18	249	248	75	50	91	341	245	316	389	251	158	249	354	235	162	179	139
19	285	81	40	89	145	87	39	353	378	264	159	290	211	104	128	178	99
20+	463	279	220	200	174	622	192	355	327	287	380	695	334	234	122	410	198
Total	17939	14749	20937	22277	16149	11512	9070	9924	14148	14078	13474	12771	9703	10444	8823	9027	11607

Age	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
2	0	0	0	1	1	0	3	1	2	0	0	1	0	0	0	0	0
3	0	0	5	11	9	8	14	15	4	11	1	0	11	0	0	0	0
4	32	29	9	29	15	18	41	31	46	15	5	10	13	7	1	0	0
5	284	322	53	73	40	76	65	85	63	77	11	22	33	3	6	1	5
6	299	1034	331	222	170	121	249	136	209	132	119	28	66	54	26	5	22
7	481	1183	846	568	338	388	301	293	313	205	130	102	44	129	48	11	39
8	910	1034	931	539	667	384	750	236	389	232	154	100	114	88	77	39	60
9	613	829	910	441	805	456	661	567	289	197	135	130	142	192	88	60	72
10	469	698	877	504	778	510	679	456	519	193	137	118	101	162	116	41	35
11	567	437	685	379	545	249	455	469	291	211	77	94	93	157	121	40	26
12	342	414	478	251	452	267	335	432	353	154	76	95	100	172	97	25	26
13	150	220	431	185	237	173	145	287	249	117	61	107	69	120	69	33	22
14	91	129	206	168	163	85	72	150	136	80	22	72	45	61	93	38	6
15	65	80	178	61	112	81	37	126	93	52	21	46	21	59	58	18	8
16	67	49	73	61	64	33	14	33	30	35	6	40	35	44	12	7	1
17	38	23	66	18	24	25	6	20	27	12	3	13	20	31	37	4	2
18	32	56	42	20	7	12	3	17	9	7	2	14	7	24	5	4	1
19	28	26	55	5	6	7	1	7	4	3	1	8	2	16	3	8	0
20+	45	43	64	18	7	6	1	8	5	3	3	2	3	14	4	5	0
Total	4513	6605	6242	3553	4439	2900	3834	3370	3030	1738	965	1004	920	1331	860	341	328

Table 4. Catch-at-age (thousands of American plaice) in NAFO 4T, revised to include unspecified flounder, assumed to be composed of 90% American plaice.

Age	1976	1977	1978	1979	1980	1981	1982	1983
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	4	17	3	0	64	0	15
5	32	105	433	0	0	68	0	185
6	466	666	1174	436	37	105	30	270
7	1362	2389	2636	1295	404	199	41	387
8	2323	2603	4900	4441	1115	869	372	451
9	2059	2426	2869	5729	3159	1093	973	473
10	2435	1952	2900	4037	2434	1327	1588	1097
11	2077	1541	2589	2472	2285	1483	1419	884
12	3005	2089	1478	1710	2555	1215	1469	1447
13	1594	776	1420	1140	1922	942	1103	1572
14	745	718	899	1252	1411	769	843	875
15	508	236	563	373	851	1214	435	655
16	580	312	242	258	498	539	420	690
17	314	191	145	162	225	703	307	615
18	274	269	82	52	103	346	256	361
19	312	88	43	93	161	88	42	406
20+	507	300	233	224	183	631	201	421
Total	18593	16665	22623	23677	17345	11656	9499	10804

Table 5. Estimates of the percentage of mobile gear catches of 4T American plaice fishery discarded at sea, according to two models. The "area effect model" weights the survey population length distribution of plaice annually in each NAFO unit area by the level of fishing. The alternative model assumes that the fishery is distributed evenly throughout NAFO 4T. RSQ refers to the R^2 of the regressions used to adjust the observed and estimated abundance at non-discarded lengths, required to estimate discards (see text). No estimate was made for 2008 due to non significant regression models.

	Area effect model		No area effect model	
Year	RSQ	% discard	RSQ	% discard
1976	0.94	77.7	0.96	78.5
1977	0.94	76.3	0.94	78.1
1978	0.86	55.6	0.84	56.0
1979	0.95	51.9	0.94	57.6
1980	0.83	68.0	0.85	63.7
1981	0.73	53.1	0.80	53.3
1982	0.88	62.5	0.93	57.5
1983	0.84	61.0	0.81	50.5
1984	0.88	29.7	0.89	42.6
1985	0.95	49.9	0.96	44.4
1986	0.94	28.0	0.95	30.7
1987	0.91	54.2	0.91	63.5
1988	0.72	53.1	0.64	57.6
1989	0.90	55.3	0.93	54.5
1990	0.92	52.2	0.92	54.9
1991	0.84	80.7	0.85	81.2
1992	0.87	52.4	0.90	59.8
1993	0.90	77.4	0.94	82.5
1994	0.95	3.5	0.95	2.6
1995	0.95	4.8	0.95	4.1
1996	0.93	7.5	0.91	9.6
1997	0.90	12.9	0.89	13.8
1998	0.91	15.2	0.90	13.5
1999	0.87	18.2	0.82	19.5
2000	0.89	10.8	0.85	12.2
2001	0.86	15.3	0.84	15.7
2002	0.92	7.1	0.89	7.8
2004	0.78	18.0	0.77	18.4
2005	0.89	11.8	0.85	11.3
2006	0.93	5.1	0.90	6.1
2007	0.67	25.9	0.62	25.1
2008	0.15*		0.09*	
2009	0.82	9.2	0.82	9.2

* non-significant regressions (P>0.06)

Table 6. Estimates of discarding rates assuming mesh sizes suggested by Halliday et al. (1989), i.e. seines using 110 mm codend mesh size; trawls using 130 mm. Estimates were made using a model that does not weight population length composition by unit area landings (comparable to last column in Table 5).

Year	% discard
1976	59.0
1977	75.7
1978	47.5
1979	54.7
1980	59.5

Table 7 Estimated discarded catch-at-age (thousands) of 4T American plaice. No estimates were possible for 2003 and 2008.

Age	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1	6	2	11	1	2	3	2	1	1	7	13	3
3	49	21	6	3	60	36	15	12	27	58	30	26	13	45	33	156	65
4	1431	803	408	170	642	186	65	81	208	187	249	297	107	233	293	1021	433
5	10047	5036	1871	1311	1967	449	460	240	407	695	427	1072	376	817	1217	2896	1326
6	18950	10866	4186	3433	4341	1195	670	515	701	898	945	2122	1258	1180	1802	4791	2668
7	12473	15426	7702	6913	6451	1959	1499	528	971	787	929	2871	1142	2183	1588	5600	3013
8	5628	7938	4959	6945	6778	1955	2842	983	1031	1208	457	2405	1610	1720	1846	4471	2704
9	4635	2949	1136	2973	2925	1655	2320	1446	1294	965	604	2028	1147	1356	1077	4846	1481
10	2691	1499	549	999	1066	893	1801	1044	1521	1114	244	1579	534	909	698	2776	1424
11	1102	706	132	374	194	375	593	1213	537	1369	295	1215	410	476	462	1977	757
12	412	322	0	119	36	179	65	635	472	979	563	1059	342	435	218	1352	524
13	0	73	0	21	11	19	5	137	175	589	289	424	299	297	162	630	286
14	115	7	0	1	16	18	0	36	40	381	290	387	251	204	34	538	158
15	24	11	5	0	0	29	7	10	10	143	152	181	85	115	41	394	96
16	0	8	0	0	0	0	0	0	0	45	96	79	11	52	4	198	67
17	12	0	0	0	0	0	0	0	0	18	19	30	9	30	2	255	14
18	0	0	0	0	0	0	0	0	0	12	10	0	0	3	0	100	17
19	0	0	0	0	0	0	0	0	0	5	9	0	0	0	2	42	6
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
24	0	0	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	57568	45667	20955	23295	24489	8953	10344	6892	7395	9455	5609	15777	7596	10056	9488	32055	15049

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	0	0	0	0	0	0	0	0	0	0		0	0	0	0		0
2	1	0	0	0	0	0	0	0	0	0		0	0	0	0		0
3	18	0	0	0	0	0	0	0	0	0		0	0	0	0		0
4	270	0	0	0	0	1	2	1	4	0		1	0	0	2		0
5	1027	4	2	5	3	5	14	5	7	1		6	2	1	7		0
6	1826	16	15	16	29	16	81	18	37	4		11	10	2	25		0
7	2115	23	27	31	44	55	64	33	39	10		21	11	7	30		1
8	1784	30	48	43	102	71	144	46	50	15		21	20	5	35		1
9	1185	24	53	38	90	72	98	65	32	14		23	9	8	20		3
10	574	22	39	30	73	59	81	43	54	11		19	10	8	23		3
11	573	11	27	14	45	22	42	40	49	15		12	7	7	12		1
12	257	9	10	10	28	18	20	16	35	7		6	4	5	9		1
13	140	1	7	5	21	8	7	9	15	3		5	2	4	3		0
14	47	1	2	2	4	4	4	0	6	3		2	1	1	2		0
15	14	0	0	1	5	2	0	0	3	1		2	0	1	1		0
16	16	0	0	0	0	1	0	1	1	0		0	0	0	1		0
17	7	0	0	0	0	0	0	0	0	0		0	0	1	0		0
18	4	0	0	0	0	0	0	0	0	0		0	0	0	0		0
19	0	0	0	0	0	0	0	0	0	0		0	0	0	0		0
20	0	0	0	0	0	0	0	0	0	0		0	0	0	0		0
21	0	0	0	0	0	0	0	0	0	0		0	0	0	0		0
24	0	0	0	0	0	0	0	0	0	0		0	0	0	0		0
Total	9859	142	229	197	445	335	557	276	332	84		127	76	49	170		13

Table 8. Landed catch-at-age of NAFO 4T American plaice, based on landings that include an estimate of the portion of unspecified flounders that are considered to be American plaice (upper panel). The lower panel shows the estimated catch-at-age of discarded plaice from the same landings.

Age	1976	1977	1978	1979	1980	1981	1982	1983
4	0	4	17	3	0	64	0	15
5	32	105	433	0	0	68	0	185
6	466	666	1174	436	37	105	30	270
7	1362	2389	2636	1295	404	199	41	387
8	2323	2603	4900	4441	1115	869	372	451
9	2059	2426	2869	5729	3159	1093	973	473
10	2435	1952	2900	4037	2434	1327	1588	1097
11	2077	1541	2589	2472	2285	1483	1419	884
12	3005	2089	1478	1710	2555	1215	1469	1447
13	1594	776	1420	1140	1922	942	1103	1572
14	745	718	899	1252	1411	769	843	875
15	508	236	563	373	851	1214	435	655
16	580	312	242	258	498	539	420	690
17	314	191	145	162	225	703	307	615
18	274	269	82	52	103	346	256	361
19	312	88	43	93	161	88	42	406
20	214	222	40	73	62	185	33	178
21	138	33	71	84	24	92	76	76
22	66	41	0	29	26	151	36	100
23	52	2	69	3	71	66	33	26
24	22	1	35	0	0	66	15	5
25	5	0	0	35	0	19	6	22
26	11	1	18	0	0	52	2	5
27	0	0	0	0	0	0	0	8
Total	18593	16665	22623	23677	17345	11656	9499	10804

	1976	1977	1978	1979	1980	1981	1982	1983
1	0	0	0	0	0	0	0	0
2	0	0	0	0	1	6	2	11
3	50	21	6	3	61	36	15	12
4	1472	814	412	172	655	190	66	81
5	10334	5105	1889	1331	2005	458	465	240
6	19499	11018	4224	3486	4425	1218	678	515
7	12845	15655	7767	7018	6578	1999	1516	528
8	5800	8073	4998	7050	6918	1997	2872	983
9	4781	3004	1144	3019	2990	1692	2342	1447
10	2778	1530	553	1016	1092	916	1815	1044
11	1138	721	133	380	200	385	597	1213
12	426	329	0	121	37	183	65	635
13	0	76	0	21	12	19	5	137
14	119	7	0	1	16	19	0	36
15	25	11	5	0	0	29	7	10
16	0	8	0	0	0	0	0	0
17	12	0	0	0	0	0	0	0
24	0	0	0	34	0	0	0	0
Total	59278	46373	21130	23653	24990	9148	10444	6893

Table 9. Geometric means of 5000 bootstrap estimates of discarded catch-at-age (thousands) of American plaice. Empty cells indicate no discarded plaice.

Age	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1		0			0	0		0		0	0	0	0	0	0	0	0
2	0	0	0	0	1	6	2	11	1	2	3	2	1	1	7	13	3
3	48	21	7	3	61	36	15	12	28	58	29	27	14	46	34	158	65
4	1418	802	420	166	650	190	65	82	212	188	243	305	114	237	301	1040	434
5	9953	5027	1927	1293	1990	459	460	245	414	696	417	1102	402	833	1251	2950	1328
6	18765	10844	4313	3383	4392	1222	670	525	713	900	920	2183	1343	1205	1855	4882	2671
7	12341	15390	7953	6799	6526	2008	1500	539	990	789	901	2957	1224	2233	1641	5712	3013
8	5560	7910	5162	6803	6854	2009	2846	1003	1053	1211	441	2486	1728	1764	1913	4561	2700
9	4571	2935	1200	2898	2956	1705	2321	1477	1325	967	582	2099	1235	1395	1118	4948	1476
10	2649	1489	583	969	1081	928	1807	1066	1561	1117	231	1639	580	937	730	2835	1415
11	1082	701	141	362	202	389	598	1239	555	1373	281	1266	446	492	484	2020	752
12	404	319	13	109	39	185	69	648	490	981	536	1106	375	450	230	1381	518
13		72	6	18	12	19	5	139	183	591	274	446	326	307	171	644	282
14	114	7		1	16	19		37	42	383	276	405	276	211	36	549	157
15	23	11	5			30	7	10	10	144	141	190	96	119	44	403	94
16		8								46	90	84	11	54	5	202	65
17	11							1	1	18	17	31	10	31	2	261	14
18										12	9		1	4		102	16
19										5	9				2	43	5
20										0							1
21																	6
24				33													
Total	56938	45534	21729	22837	24779	9207	10367	7035	7578	9481	5398	16328	8181	10318	9825	32705	15016

Age	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	0			0	0	0	0	0	0					0	0		0
2	1	0	0	0	0	0	0	0	0	0		0	0	0	0		0
3	18	0	0	0	0	0	0	0	0	0		0	0	0	0		0
4	273	0	0	0	0	1	2	1	4	0		1	0	0	2		0
5	1040	4	2	5	3	6	14	6	7	1		6	2	1	7		0
6	1851	16	15	16	30	16	81	19	37	4		11	10	2	26		1
7	2144	25	28	31	45	56	63	34	40	10		21	11	7	31		1
8	1809	32	49	45	104	72	144	48	52	16		20	20	5	36		1
9	1203	26	54	41	92	72	97	67	33	14		23	10	8	21		4
10	583	24	40	33	74	60	82	44	56	11		19	11	8	24		3
11	582	12	28	15	45	22	42	41	51	15		12	8	7	13		1
12	261	10	10	11	28	18	20	17	38	7		5	4	5	9		1
13	143	2	7	6	22	7	7	10	16	4		5	2	4	3		0
14	48	1	2	2	4	4	4	1	7	3		2	1	1	2		0
15	15	0	0	1	5	3	0	0	3	1		2	0	1	1		0
16	16	0	0	0	0	1	0	1	1	0		0	0	0	1		0
17	8	0			0			0	0	0		0	0	1	0		0
18	4	1	0	0					1			0	0	0	0		0
19	0	0	0	0						0							0
20			0		1								0	0			
21																	
24																	
Total	9999	154	237	207	455	339	557	289	346	86		126	80	49	176		13

*Table 10. Coefficients of variation (%) of bootstrap estimates of discarded catch-at-age of American plaice. Discard estimates were made in units of 1000 plaice. Negative values of the cv are associated with mean discard estimates of less than 1000 plaice. Extreme values of the c.v. are denoted by symbols: * signifies less than -100%; + signifies greater than 100%.*

age	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1		-1.2			-3.4	-4.4		-6.5		-1.9	-2.2	-2.4	-6.2	-1.5	-2.7	-6.3	-4.9
2	-2.7	-4.2	-6.7	-2.3	*	5.8	17.7	10.3	21.8	6.8	10.3	12.3	87.6	*	5.2	3.8	13.4
3	1.5	2.5	9.4	52.0	3.7	3.0	2.8	6.5	2.7	1.4	4.0	3.0	10.0	2.3	3.1	1.9	3.8
4	0.8	1.1	3.0	2.5	2.4	2.1	1.8	3.6	1.6	1.2	2.1	1.8	5.8	1.6	1.9	1.4	2.6
5	0.6	0.9	2.5	1.4	2.0	1.9	1.3	3.0	1.4	1.0	1.9	1.4	4.7	1.4	1.5	1.3	2.1
6	0.6	0.8	2.3	1.3	1.9	1.6	1.2	2.6	1.4	1.0	1.9	1.4	3.9	1.5	1.6	1.2	2.0
7	0.7	0.9	2.4	1.3	2.0	1.6	1.1	2.5	1.5	1.1	2.2	1.4	4.2	1.5	1.9	1.3	2.2
8	0.9	1.1	3.1	1.6	2.3	1.9	1.1	2.5	1.6	1.1	2.9	1.6	4.3	1.7	2.0	1.3	2.4
9	1.0	1.4	4.9	2.1	3.3	2.2	1.2	2.4	1.8	1.1	2.9	1.7	4.8	2.1	2.3	1.4	2.9
10	1.2	1.9	6.1	3.1	4.7	3.3	1.6	2.7	1.9	1.2	4.6	2.0	5.9	2.4	2.9	1.5	3.3
11	1.5	2.2	11.1	4.0	10.0	4.0	2.2	3.0	2.7	1.3	4.3	2.3	6.9	2.9	3.2	1.6	3.7
12	1.9	2.8	52.6	7.8	17.7	5.4	5.9	3.3	3.0	1.5	3.7	2.6	7.2	3.0	4.3	1.7	4.5
13		5.6	73.6	25.7	38.3	11.3	23.8	6.4	4.5	1.7	4.3	3.8	7.8	3.1	5.0	1.9	5.0
14	2.0	13.9		+	10.2	10.1	0.0	6.1	5.5	2.2	4.3	3.3	8.2	4.0	9.9	2.0	5.2
15	6.3	11.2	16.9			4.3	11.8	14.6	9.5	2.6	6.5	4.0	11.2	5.2	8.0	2.2	7.0
16		9.1								3.2	6.3	6.5	45.5	6.4	30.1	2.4	7.9
17	9.3							*	*	2.6	13.0	4.8	31.8	10.1	56.4	2.5	15.0
18										3.9	13.0		*	19.8		3.2	13.8
19										9.2	4.7				+	4.8	76.5
20										-82.3							+
21																	19.0
24				2.9													

age	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	-2.5			-0.7	-1.3	-1.0	-1.4	-1.1	-1.5					-0.7	-4.4		-1.0
2	31.5	-1.2	-1.0	-1.3	-2.0	-1.7	-13.9	-1.4	-2.2	-1.1		-2.0	-1.6	-1.2	-16.5		-1.9
3	3.3	-2.8	-1.9	-36.7	-6.8	-2.4	-19.8	-2.1	-31.8	-9.6		-11.2	-32.1	-1.5	-41.9		-3.0
4	1.7	-4.4	-19.6	-49.7	-52.2	+	+	+	38.4	-23.5		*	-41.2	-30.9	88.2		-3.9
5	1.4	41.9	84.5	31.8	55.0	20.8	16.8	30.2	27.7	*		36.2	+	*	24.3		-37.9
6	1.3	21.0	22.6	17.9	15.0	14.0	8.1	17.0	12.3	41.3		24.3	22.9	+	15.6		*
7	1.4	19.3	20.4	14.9	11.1	8.4	9.8	14.4	14.2	24.8		19.4	21.1	34.1	15.1		+
8	1.4	19.3	15.8	13.4	10.2	9.1	8.0	11.9	12.6	19.4		19.7	17.4	43.7	14.2		+
9	1.6	19.8	15.1	14.3	10.5	10.3	9.3	11.2	13.3	20.7		19.1	24.0	30.4	17.8		53.4
10	2.0	20.9	16.0	15.4	12.0	10.3	10.1	12.9	13.7	23.0		20.3	22.9	26.7	17.2		50.5
11	2.0	28.2	15.5	20.6	14.6	15.6	12.6	14.0	11.8	19.1		23.4	26.3	30.5	22.0		*
12	2.3	32.4	26.1	23.1	16.2	14.3	15.3	20.2	15.0	27.1		40.0	42.7	37.7	24.2		+
13	2.8	+	27.9	31.3	15.7	27.1	23.4	28.8	22.6	46.3		41.1	+	43.4	57.8		-93.2
14	3.9	+	+	74.5	29.1	31.5	26.5	+	27.4	51.4		+	+	+	+		-60.3
15	5.6	-67.2	-98.9	+	34.4	46.2	*	*	48.1	*		+	-54.8	*	*		-38.2
16	5.4	-56.4	-75.9	-34.2	-59.4	*	*	*	*	-54.7		-38.9	-39.6	-47.5	+		-27.0
17	7.4	-51.3			-82.5			-77.2	-56.3	-42.0		-25.2	-65.4	*	-24.9		-26.9
18	13.2	*	-82.7	-32.1					*			-73.9	-31.6	-34.1	-88.9		-27.7
19	-77.2	-65.4	-57.1	-45.5						-38.0							-54.5
20			-80.3		*								-38.3	-23.1			
21																	
24																	

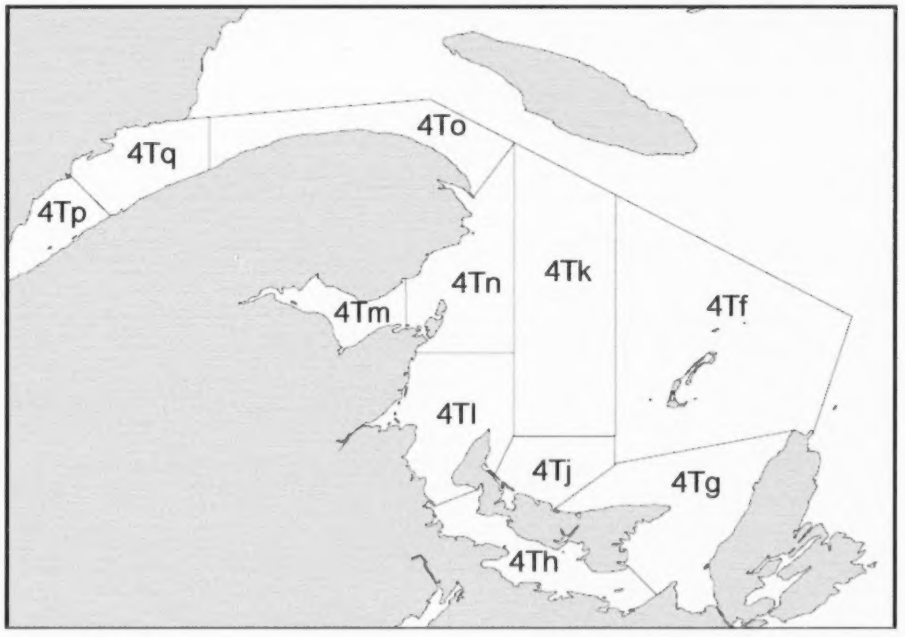

Figure 1. The southern Gulf of St. Lawrence showing the unit area designations of NAFO 4T.

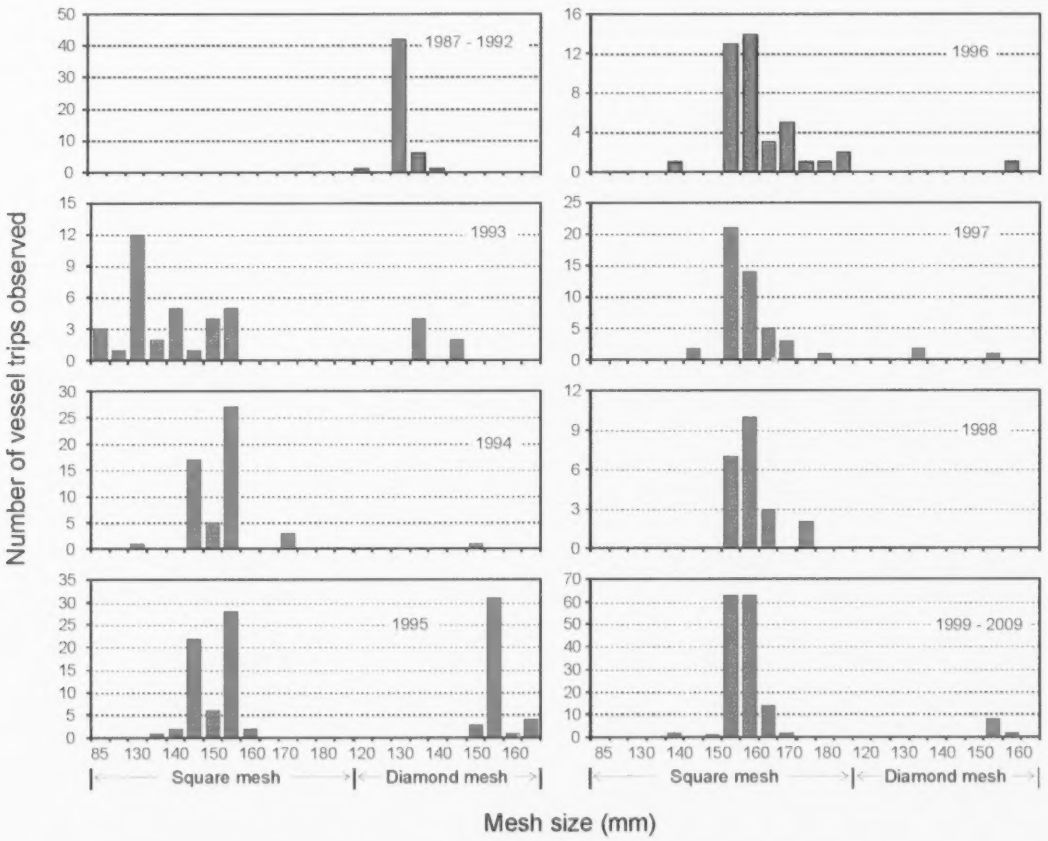

Figure 2. Codend mesh sizes used by mobile gear (seines and trawls) in NAFO 4T, 1987 to 2009. Mesh sizes were averaged by individual vessel trip before being counted by year or group of years. Changes to the regulations on minimum mesh size were made in 1993, 1994 and 1995 (see text).

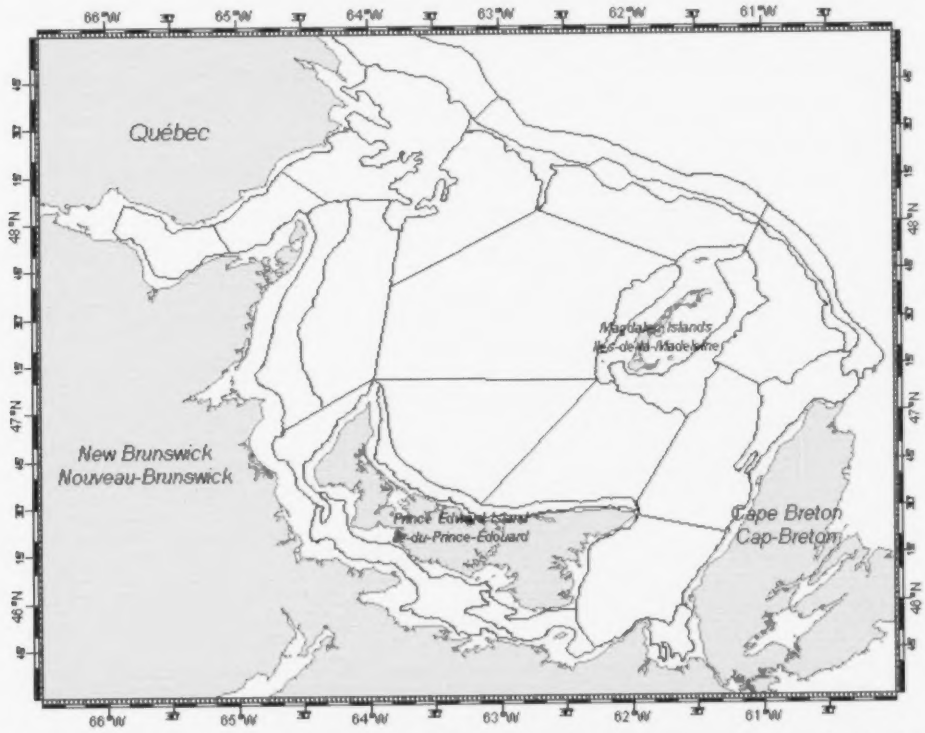

Figure 3. Southern Gulf of St. Lawrence (NAFO Division 4T) showing stratum boundaries in the annual trawl survey.

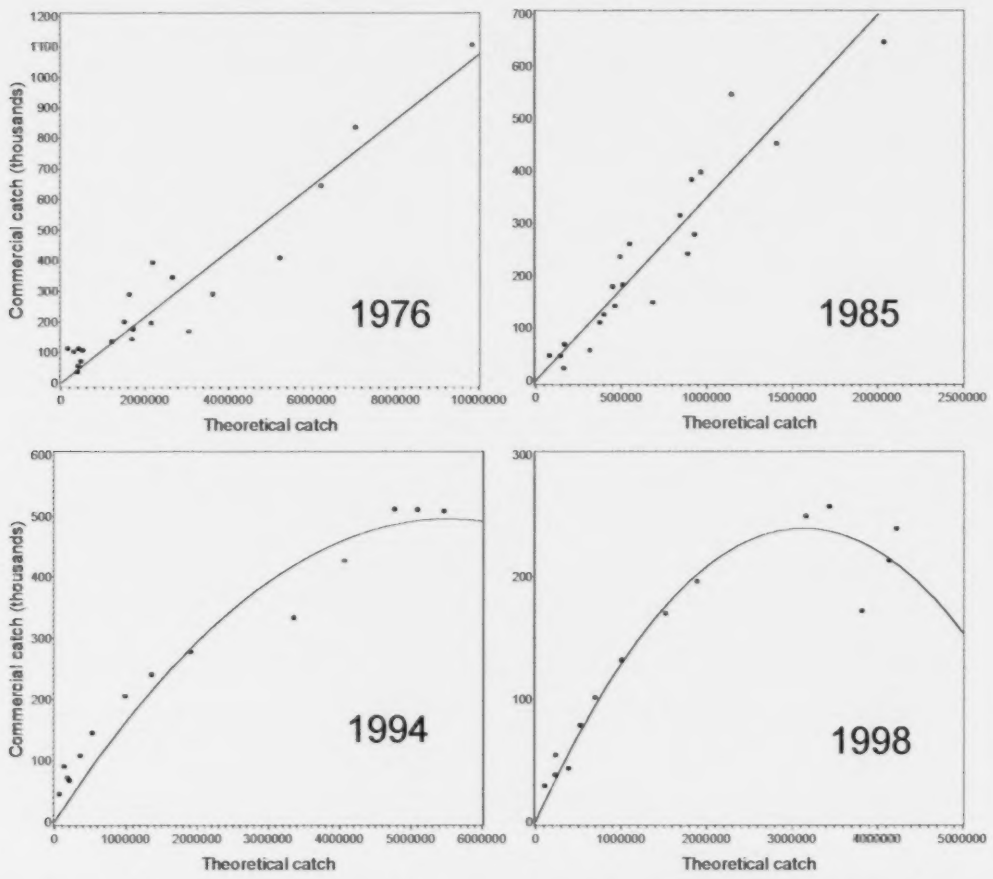

Figure 4. Plots of commercial catch-at-length, observed and estimated from survey data and mesh selectivity (theoretical), for selected years. Linear regressions were fitted to the 1976 and 1985 data and quadratic regression models were fitted to the 1994 and 1998 data.

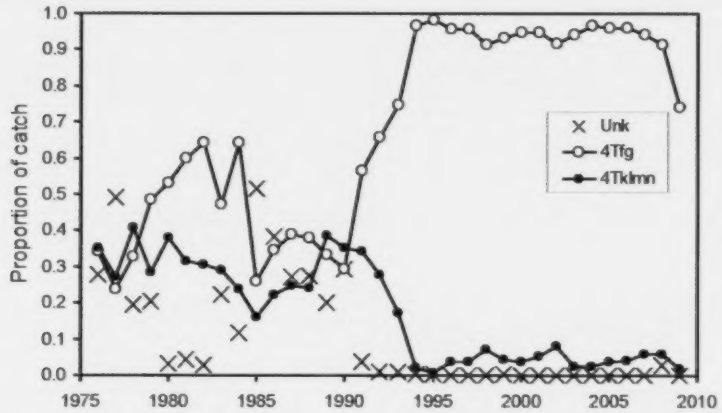

Figure 5. The proportion of landed catches found in the main fishing areas of NAFO 4T: in unit areas of eastern 4T (4Tfg) and in western 4T (4Tklmn). Until 1990, some landings were made without reporting the unit area from which they were made (unk).

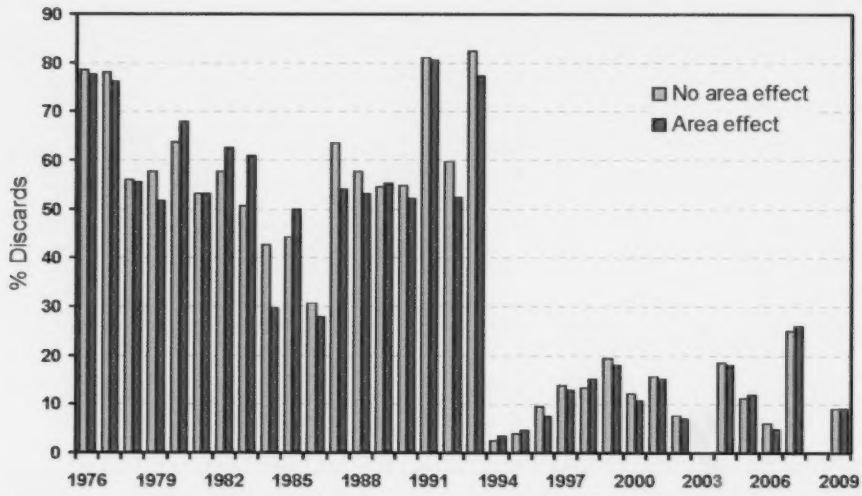

Figure 6. Total rates of estimated discarding based on a model that takes into account the spatial effect of fishing activity (area effects) and a model that does not take into account area effects due to fishing activity.

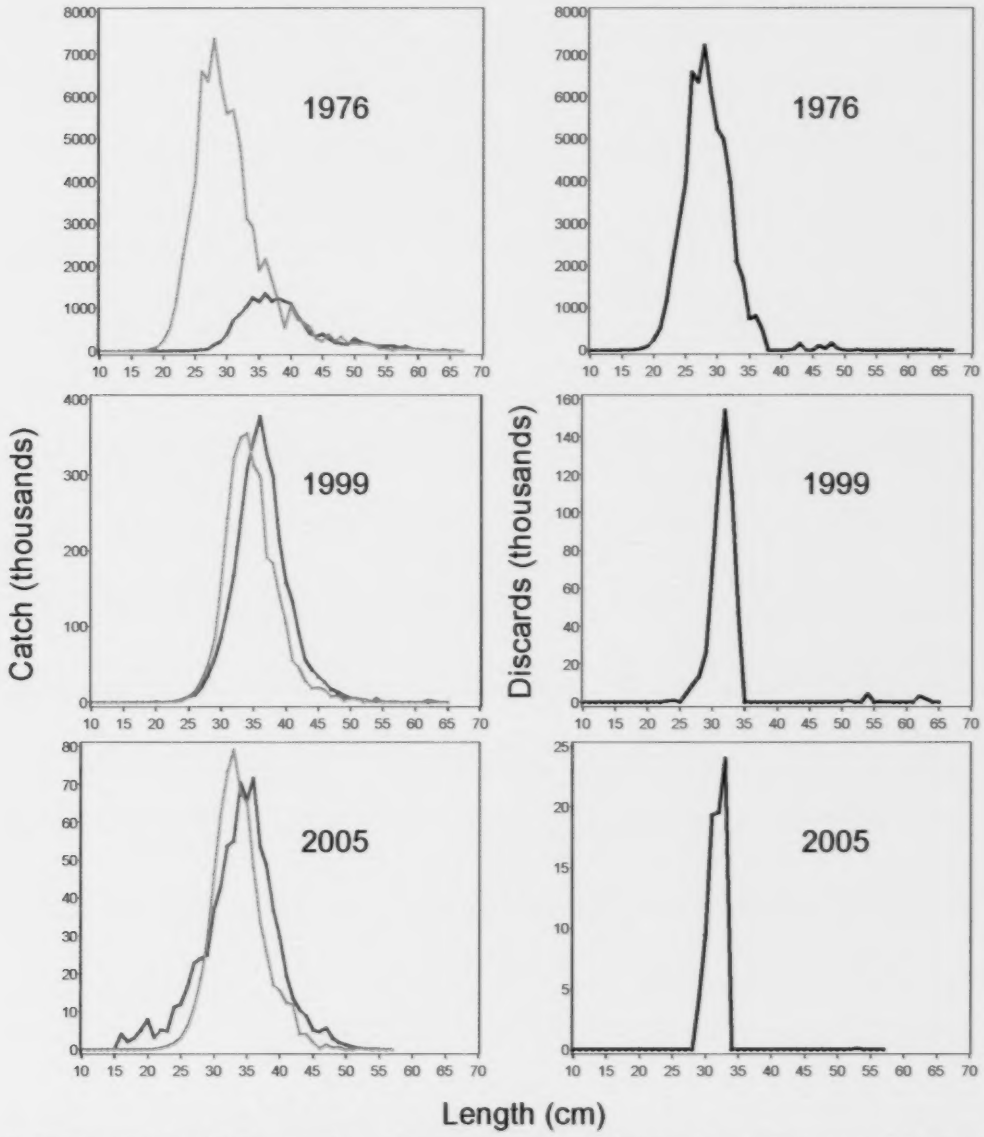

Figure 7. Left graphs: length frequencies of landed catches of 4T plaice in selected years (blue line) and the theoretical catch (red line; see text). The graphs at right show the estimated length composition of discards, i.e. the positive difference between the theoretical catch and the observed landed catch.

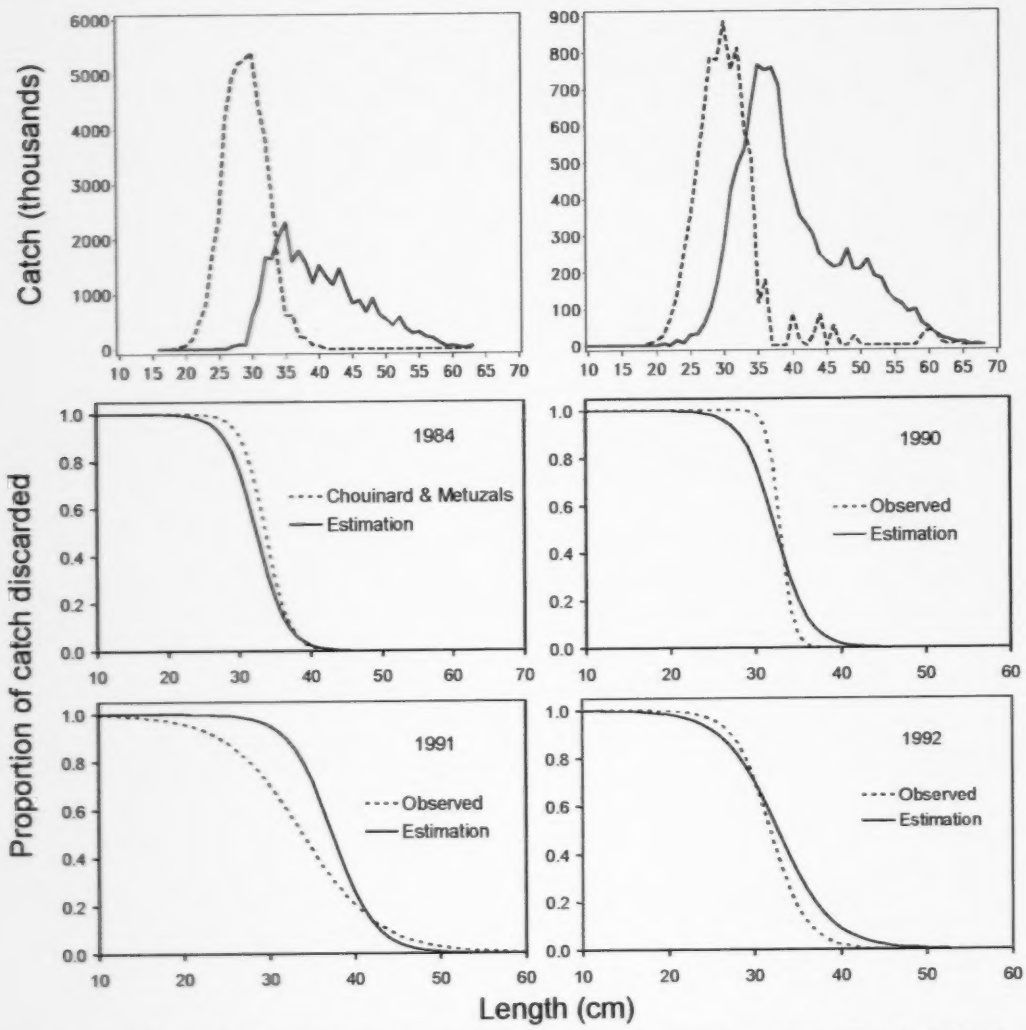

Figure 8. Upper left graph shows the observed discards (broken line) and retained catch (solid line), estimated by Chouinard and Metuzals (1985). Upper right graph shows estimated discards (broken line) and commercial catch (solid line) from port sampling of plaice catches in 1984. Remaining graphs compare logistic regressions from observed and estimated rates of discarding in the 1984 and 1990-1992 fisheries.

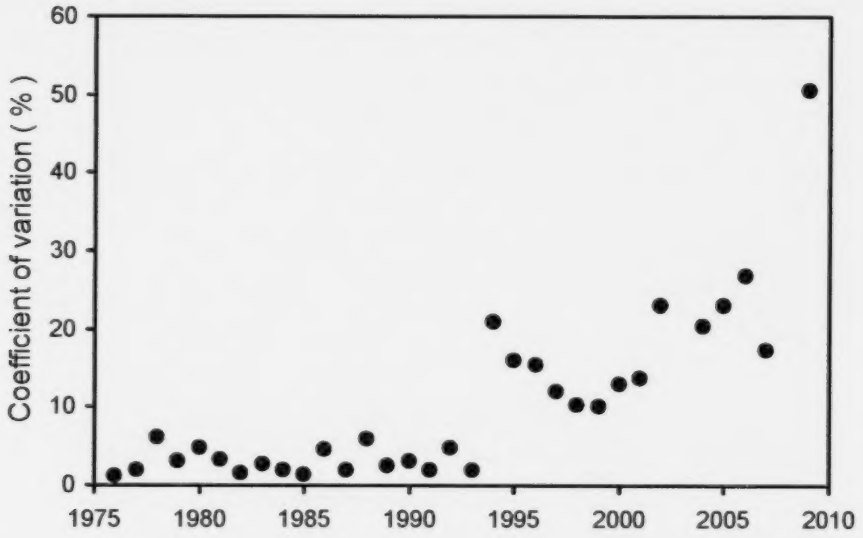

Figure 9. Coefficients of variation on age-10 plaice resulting from 5,000 bootstrap estimates of discarding. No estimates were made for 2003 and 2008.